# Ventilation of Mechanical Refrigerator Cars To Prevent Carbon Dioxide Accumulation and Brown Stain in Lettuce Loads

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# Ventilation of Mechanical Refrigerator Cars To Prevent Carbon Dioxide Accumulation and Brown Stain in Lettuce Loads

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## SUMMARY

Lettuce was shipped from California to the east coast in mechanically refrigerated railcars with various venting systems to prevent the accumulation of injurious concentrations of respiratory carbon dioxide ($CO_2$). Lettuce shipped in cars with modified atmospheres also was studied.

Propping open one of the two water drains at each end of the car prevented the accumulation of dangerous levels of $CO_2$; many cars with drains in the normal closed position accumulated excessive $CO_2$ (3.0 to 4.2 percent at destination). $CO_2$ levels in the modified atmosphere cars ranged from 0.6 to 2.2 percent at destination.

Transit temperatures of the lettuce were a satisfactory range in all test cars.

Incidence of brown stain was insignificant i the cars with drains open, but the disorder a fected about 40 percent of the lettuce in th control cars with drains closed and about 3 percent of the heads in the modified atmospher cars.

Decay, butt discoloration, tipburn, and ri discoloration were not affected by the car at mosphere, nor was the overall, external appear ance of the lettuce, with or without wrappe leaves.

## BACKGROUND

Increased concentrations of carbon dioxide ($CO_2$) have been shown in both laboratory and shipping tests to cause brown stain, a physiological disorder of lettuce (*2, 6, 7, 8*).[1] Accumulations of $CO_2$ in railcars of lettuce have been detected at east coast destinations since 1967, and concentrations as high as 6.6 percent have been observed (*4, 6*). $CO_2$ levels below 2 percent have resulted in brown stain in some rail shipments to the east coast, but the disorder is more common when the levels are above 2 percent (*6*).

An accompanied transcontinental test shipment of lettuce in 1970 showed that three out of eight conventional railcars of lettuce aver aged 2.7 percent $CO_2$, or higher, during transi (*6*). There was a positive correlation betwee the $CO_2$ level and the incidence of brown stai in the eight cars. This test also showed tha with modified atmospheres in which the oxyge ($O_2$) was low and the carbon monoxide (CO) level was increased had more brown stain a comparable $CO_2$ levels than conventional cars Subsequent laboratory tests showed that the combination of low $O_2$ and added CO in the presence of increased $CO_2$ resulted in an exceptionally high incidence of brown stain (*8*).

Three separate studies were conducted in 1970 and 1971 to develop practical methods of preventing the accumulation of dangerous levels of $CO_2$ in conventional railcars of lettuce. The

[1] Italic numbers in parentheses refer to Literature Cited, p. 8.

first two were preliminary and data for those are presented in the Appendix. The third study involved 28 commercial shipments of lettuce from California to the east coast, in which the water drains of 10 cars were propped open to partially ventilate the loads. Modified atmosphere cars also were studied in these tests.

## METHODS AND MATERIALS

### Railway Equipment

Twenty-eight Pacific Fruit Express (PFE) mechanically refrigerated railcars of the 450,000 to 460,000 series were loaded with lettuce and shipped between July 13 and October 13, 1971. Most of the shipments were from Salinas, Calif., to the Hunts Point Market, New York, but a few cars were loaded at Brentwood, Calif., and two cars terminated in Philadelphia, Pa. Most of the cars were loaded with 1,140 cartons; some had 1,152. The thermostats were set at 34°F. on all cars.

### Test Variables

In 10 of the 28 test cars, one of the two water drains at each end of the car was propped open during transit in an effort to prevent the accumulation of $CO_2$. Ten cars (the controls) were not altered and their drains were left in the normal, closed condition. The other eight cars were treated at shipping point by the Transfresh Corporation to achieve a modified atmosphere. This process involves flushing out the air in the loaded car with nitrogen until the $O_2$ level is reduced to about 2 percent and then introducing about 1½ percent CO. About 240 pounds of lime are placed in the load compartment to absorb respiratory $CO_2$ produced by the lettuce. Finally, the car is tightly sealed, and no further attempt is made to control the atmosphere during transit. This commercial treatment is used in many transcontinental lettuce shipments.

Except for the first four cars, all test cars were shipped in series of three per day; consisting of one car of each variable.

### Test Packages

Three test cartons of naked-pack lettuce were placed in the top layer of each car, near the doorway. Lettuce for the nine test packages on a given day was from the same field.

### Atmosphere Analysis

A ¼-inch plastic tube was inserted into the load compartment of each test car at shipping point to permit atmosphere sampling. At destination, the atmosphere in each car was analyzed by United States Department of Agriculture (USDA) personnel before the car doors were opened. Atmospheres were analyzed for $0_2$ and $CO_2$ with a portable Fyrite volumetric gas analyzer or an Orsat-type gas analyzer. CO in the modified atmosphere cars was analyzed with an Orsat-type analyzer

When possible, test car atmospheres also were measured by USDA personnel during train stops in Chicago.

### Temperature Measurement

Ryan recording thermometers were placed in two of the three test packages in each car. A thermometer also was attached near the ceiling, at the doorway, to record inside air temperatures.

### Market Quality Evaluation

After arrival, the test cartons of lettuce were taken to the USDA's Market Pathology Laboratory at Belle Mead, N.J. Half of the lettuce from each carton was evaluated soon after arrival, and the remaining half was evaluated after it had been held in air an additional 4 days at 50° F.

The quality of the lettuce was evaluated by examining each head, leaf by leaf. Incidence and severity of brown stain, russet spotting, pink rib, decay, tipburn, and butt discoloration were determined. The severity of the disorders was rated on a scale of 1 to 5 where 1 was none; 2, trace; 3, slight; 4, moderate; and 5, severe. The general appearance of the heads, before and after removal of the wrapper leaves, also was determined using a scale of 1 to 5 where 1 was

unsalable; 2, poor; 3, fair; 4, good; and 5, excellent. Butt discoloration was not considered when making general appearance ratings because the discolored portion of the butt is usually trimmed at the retail level.

### Statistical Analyses

Data were evaluated by analysis of variance for a split plot using the different test series as replications, car and drain variations as wh plots, and examinations as split plots. The s nificance of differences among treatments determined by Duncan's Multiple Rang All statistical analyses are based on eig er than 10 replications because no n atmosphere cars were shipped during t two test series.

## RESULTS

### Atmospheres in Test Cars

*Cars with drains closed (normal).*—At destination, $CO_2$ ranged from 0 to 4.2 percent among the 10 cars in which the drains were left closed (table 1). $CO_2$ built up to injurious levels in five of these cars, ranging from 3.0 to 4.2 percent. Atmospheres taken at Chicago in three of these 10 cars were in general agreement with those taken at destination. (Chicago data not shown.)

The lowest $O_2$ level in any of the cars with drains closed was 15.4 percent, which was not low enough to affect the lettuce.

*Cars with drains open.*—Propping one drain open at each end of the car during transit prevented the accumulation of injurious levels of $CO_2$. The highest $CO_2$ level found at destination in any of these cars was 0.5 percent (car 10b, table 1). No measurable $CO_2$ was found in eight of the 10 cars at destination.

*Modified atmosphere cars.*—$CO_2$ levels in the modified atmosphere cars were generally lower than those in the cars with drains closed, but higher than those in cars with drains open (table 1). $CO_2$ levels in the eight Transfresh cars ranged from 0.6 to 2.2 percent and averaged 1.4 percent at destination. The average $CO_2$ level in these cars was only about one-third as high as that of Transfresh cars tested in 1967 and 1968 (*4*), which indicates an improvement in $CO_2$ scrubbing techniques.

$O_2$ ranged from 2.2 to 9.6 and averaged 5.0 percent at destination in the modified atmosphere cars. CO averaged 0.4 percent.

### Transit Temperatures

Opening the drains did not adversely affect temperatures in the cars (table 2). Test lettuce temperatures averaged 36° F. in the cars drains opened and 37° in the control cars the drains in the normal, closed position. temperatures of lettuce ranged from 33° t in the individual cars with dr 34° to 39° in the control car 39° in the modified atmos

Inside air temperatures test packages averaged 1° the average lettuce temperatu types of cars.

### Market Quality of Lettu

*Brown stain.*—On arrival, about 3 the lettuce from the cars with drains brown stain, whereas 36 percent of from the cars with drains clo stain, and about 32 percent c modified atmosphere cars h (table 3). Typical brown stain i

correlated with the level of $CO_2$, and n brown stain occurs at a given elevated leve $CO_2$ when $O_2$ is low and CO is present when these gases are at more normal le (*6, 7, 8*).

The small amount of brown stain reporte the cars with drains open (cars 3b and 8b, t 1) was probably a misidentification as no was found in these cars at destination and s forms of $CO_2$ injury resemble other ph logical disorders of lettuce (*3*). The incid of brown stain did not increase signific during the 4 days at 50° F. in air.

TABLE 1.—*Atmosphere composition and brown stain of lettuce in test cars shipped from California to the East coast 1971*[1]

| Test series [2] | Conventional cars | | | | | | | Modified atmosphere cars | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Drains closed (normal) | | | | Drains open [3] | | | | Drains and car sealed [4] | | | | |
| | Test car | Atmosphere | | Brown stain [5] | Test car | Atmosphere | | Brown stain [5] | Test car | Atmosphere | | | Brown stain [5] |
| | | $CO_2$ | $O_2$ | | | $CO_2$ | $O_2$ | | | $CO_2$ | $O_2$ | CO | |
| | *No.* | *Percent* | *Percent* | *Percent* | *No.* | *Percent* | *Percent* | *Percent* | *No.* | *Percent* | *Percent* | *Percent* | *Percent* |
| A | 1a | 1.0 | 20.0 | 0 | 1b | 0 | 21.0 | 0 | ------ | ------ | ------ | ------ | ------ |
| B | 2a | 1.5 | 19.5 | 0 | 2b | 0 | 21.0 | 0 | ------ | ------ | ------ | ------ | ------ |
| C | 3a | 1.0 | 20.0 | 80.8 | 3b | 0 | 21.0 | 5.8 | 3c | 0.9 | 2.2 | 0.2 | 64.2 |
| D | 4a | 4.0 | 17.0 | 50.0 | 4b | 0 | 21.0 | 0 | 4c | .6 | 6.4 | .3 | 30.8 |
| E | 5a | 0 | 21.0 | 0 | 5b | 0 | 21.0 | 0 | 5c | 1.0 | 2.5 | .4 | 33.3 |
| F | 6a | 1.9 | 18.9 | 5.8 | 6b | .3 | 20.8 | 0 | 6c | 1.8 | 2.6 | .4 | 8.3 |
| G | 7a | 4.2 | 15.4 | 30.8 | 7b | 0 | 21.0 | 0 | 7c | 2.2 | 9.6 | .4 | 22.5 |
| H | 8a | 3.5 | 17.0 | 47.5 | 8b | 0 | 21.0 | 2.5 | 8c | 2.0 | 5.8 | .2 | 50.0 |
| I | 9a | 4.0 | 17.0 | 94.2 | 9b | ------ | ------ | 0 | 9c | 1.4 | 5.2 | .4 | 27.5 |
| J | 10a | 3.0 | 18.0 | 30.8 | 10b | .5 | 20.5 | 0 | 10c | 1.5 | 5.5 | .5 | 22.5 |
| Average | ------ | 2.4 | 18.4 | 34.0 | ------ | .1 | 20.9 | .8 | ------ | 1.4 | 5.0 | .4 | 32.5 |

[1] Atmospheres taken at destination with portable volumetric gas analyzers from plastic tube extending into load compartment of the cars.
[2] Cars within a test series were shipped on the same day and contained test packages from the same field.
[3] One water drain propped open at each end of car.
[4] Hydrated lime (240 pounds) placed in load compartment.
[5] Percentage of heads rated 2.5 (trace to slight) or higher at the second examination.

TABLE 2.—*Transit temperatures of lettuce in test cars shipped from California to the east coast, 1971*

| Test series [1] | Conventional cars | | | | | | Modified atmosphere cars; drains and car sealed [3] | | |
|---|---|---|---|---|---|---|---|---|---|
| | Drains closed (normal) | | | Drains open [2] | | | | | |
| | Test car | Lettuce temperature [4] | Car air temperature [5] | Test car | Lettuce temperature | Car air temperature | Test car | Lettuce temperature | Car air temperature |
| | *No.* | *°F.* | *°F.* | *No.* | *°F.* | *°F.* | *No.* | *°F.* | *°F.* |
| ---------- | 1a | 36 | 35 | 1b | 37 | 36 | ------ | ------ | ------ |
| ---------- | 2a | 38 | 36 | 2b | 36 | 32 | ------ | ------ | ------ |
| ---------- | 3a | 36 | 32 | 3b | 35 | 33 | 3c | 38 | 36 |
| ---------- | 4a | 37 | 35 | 4b | 35 | 31 | 4c | 34 | 33 |
| ---------- | 5a | 36 | 35 | 5b | 33 | 30 | 5c | 37 | 36 |
| ---------- | 6a | 39 | 38 | 6b | 37 | 33 | 6c | 37 | ------ |
| ---------- | 7a | 37 | 36 | 7b | 37 | 36 | 7c | 39 | 38 |
| ---------- | 8a | 34 | 33 | 8b | 39 | 36 | 8c | 37 | 35 |
| ---------- | 9a | 36 | 33 | 9b | 34 | ------ | 9c | 37 | 36 |
| ---------- | 10a | 37 | 35 | 10b | 38 | 35 | 10c | 38 | 36 |
| erage---------- | ------ | 37 | 35 | ------ | 36 | 34 | ------ | 37 | 36 |

[1] Cars within a test series were shipped on the same day and contained test packages from the same field.
[2] One water drain propped open at each end of the car.
[3] Hydrated lime (240 pounds) placed in load compartment.
[4] Average temperature of test cartons in top layer at doorway during transit.
[5] Average temperature of car air, inside at ceiling near doorway, during transit.

The average severity ratings for brown stain re reduced to essentially "none" (1.1) by ening the drains in the cars (table 4). Sever- ratings for brown stain averaged about 2 in control cars and in the modified atmosphere rs. The range of the brown stain ratings oth examinations) was 1.0 to 1.7 for cars th drains open, 1.0 to 3.6 for cars with drains sed, and 1.2 to 2.8 for the modified atmos- ere cars. The severity of brown stain did not crease during the 4 days at 50° F.

*Russet spotting.*—Russet spotting was essen- lly absent in lettuce from all three types of rs at the first examination (tables 3 and 4), t it developed in lettuce from all types of rs during the subsequent holding period. The allest increase in russet spotting was in tuce shipped in the modified atmosphere cars. is is in agreement with other studies which ve shown that low $O_2$ inhibits the develop- nt of russet spotting (*1, 5, 6*).

*Decay.*—On arrival, about 3 percent of the heads had decay (table 3), with no significant difference in lettuce from the three types of cars. Decay increased in all lots to about 20 percent during 4 days at 50° F.

TABLE 3.—*Incidence of certain disorders and external appearance of lettuce shipped in cars with water drains open, in cars with drains normally closed, and in modified atmosphere cars from California to east coast markets, 1971*

| Car variations and time of examination [1] | Heads rated "good" or better [2] | | Heads with indicated disorders [3] | | | |
|---|---|---|---|---|---|---|
| | With wrapper leaves | Without wrapper leaves | Decay | Russet spotting | Pink rib | Brown stain |
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| rains open: | | | | | | |
| On arrival | [4] 25.8 b | 61.4 b | 2.7a | 0 a | 7.3a | 3.1a |
| 4 days after arrival | 0 a | 21.4a | 22.8 b | 11.8 bc | 22.2 b | 1.0a |
| rains closed: | | | | | | |
| On arrival | 25.3 b | 56.4 b | 3.4a | 0 a | 4.5a | 36.0 b |
| 4 days after arrival | .6a | 17.8a | 19.4 b | 18.9 c | 18.4 b | 42.5 b |
| odified atmosphere cars: | | | | | | |
| On arrival | 25.4 b | 59.7 b | 2.3a | .3a | 5.5a | 31.6 b |
| 4 days after arrival | .3a | 23.5a | 20.1 b | 8.0ab | 12.4a | 32.4 b |

[1] Drains open—one of the two water drains open at each end of car; drains closed— all four water drains closed; modified nosphere cars—all car openings tightly closed, car atmosphere modified at shipping point; see text for details.
[2] Percentage of heads rated 4.0 or higher on a scale where 1 is unsalable; 2, poor; 3, fair; 4, good; 5, excellent.
[3] Percentage of heads rated 2.5 or higher on a scale where 1 is none; 2, trace; 3, slight; 4, moderate; 5, severe.
[4] Means within a column, not followed by the same letter, differ significantly at the 5-percent probability level.

Average severity ratings for decay were also e same in lettuce from the three types of cars able 4).

*Butt discoloration.*—Butt discoloration at ne of arrival was rated "slight" in lettuce om each of the three types of cars (table 4). scoloration increased uniformly in all lots of ttuce during the subsequent holding period. the second examination, all lots of lettuce ere rated "moderate" to "severe" for dis-loration.

*Pink rib.*—At the time of arrival, about 5 to percent of the lettuce heads had pink rib ted 2.5 or higher, with no significant differ-ce among the three types of cars (table 3). in previous tests, pink rib increased during bsequent holding (*4, 5, 6, 7*). Pink rib in-eased significantly less in lettuce from the odified atmosphere cars than in that from the ner cars. Average severity ratings for pink of lettuce from the modified atmosphere rs also were significantly lower at the second examination than were the ratings for lettuce from the other two types of cars (table 4).

Previous shipping tests also have indicated that Transfresh modified atmospheres tend to inhibit pink rib (*4*). Some laboratory studies (*7*) have indicated that low $0_2$ does not reduce pink rib, while others indicate that it increases the disorder (*1, 2*). Therefore, it appears that the added CO in the Transfresh cars may reduce pink rib in lettuce.

*Other disorders.*—Neither tipburn nor rib discoloration were affected by the transit conditions.

*Appearance of lettuce with wrapper leaves.*—At time of arrival, about one-fourth of the heads from each type of car was rated "good" or better (table 3). After 4 days at 50° F., less than 1 percent of the heads were rated "good" from each of the three types. Average ratings for general appearance indicated the same finding, that there was no difference in appearance

TABLE 4.—*Market quality ratings of lettuce shipped in cars with water drains opens, cars with drains normally closed, and modified atmosphere cars from California to east coast markets, 1971*

| Car variations and time of examination [1] | Appearance ratings of heads [2] | | Severity ratings for indicated disorders [3] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | With wrapper leaves | Without wrapper leaves | Butt discoloration | Decay | Tipburn | Russet spotting | Rib discoloration | Pink rib | Brown stain |
| | *Rating* | *Rating* | *Rating* | *Rating* | *Rating* | *Rating* | *Rating* | *Rating* | *Rating* |
| Drains open: | | | | | | | | | |
| On arrival | [4] 3.3 b | 3.6 b | 3.2a | 1.1a | 1.2a | 1.0a | 1.0a | 1.2 b | 1.1a |
| 4 days after arrival | 2.4a | 3.1a | 4.8 b | 1.6 b | 1.3a | 1.3ab | 1.1a | 1.5 e | 1.1a |
| Drains closed: | | | | | | | | | |
| On arrival | 3.3 b | 3.6 b | 3.3a | 1.1a | 1.2a | 1.0a | 1.1a | 1.1a | 2.0 b |
| 4 days after arrival | 2.5a | 3.1a | 4.7 b | 1.5 b | 1.3a | 1.5 b | 1.0a | 1.5 d | 1.2 b |
| Modified atmosphere cars: | | | | | | | | | |
| On arrival | 3.4 b | 3.7 b | 3.3a | 1.1a | 1.3a | 1.0a | 1.0a | 1.2 b | 1.9 b |
| 4 days after arrival | 2.5a | 3.1a | 4.8 b | 1.6 b | 1.4a | 1.2ab | 1.0a | 1.3 c | 1.9 b |

[1] Drains open—one of the two water drains open at each end of car; drains closed—all four water drains closed; modified atmosphere cars—all car openings tightly closed, car atmosphere modified at shipping point, see text for details.

[2] Rating scale: 1, unsalable; 2, poor; 3, fair; 4, good; 5, excellent.

[3] Rating scale: 1, none; 2, trace; 3, slight; 4, moderate; 5, severe.

[4] Means within a column, not followed by the same letter, differ significantly at the 5-percent probability level.

among the lots shipped in the three types of cars (table 4).

*Appearance of lettuce without wrapper leaves.*—Trimming the wrapper leaves improved the appearance of all lots of lettuce about equally. At the first examination, about 60 percent of the heads were rated "good" or better after trimming (table 3). At the second examination, about 18 to 24 percent of the heads were rated "good" or better, with no difference in lettuce from the three types of cars.

As would be expected, average ratings for appearance were poorer at the second than at the first examination (significant at the 5-percent level, table 4), but there was no difference attributable to the type of car in which the lettuce was shipped.

## DISCUSSION

These and previous (*6*) shipping tests indicate that injurious levels of $CO_2$ develop in about ⅓ to ½ of the conventional mechanically refrigerated railcars of lettuce shipped from California to east coast markets. These elevated levels of $CO_2$ cause brown stain in many lettuce shipments. These tests show that the accumulation of $CO_2$, and thus the development of brown stain, can be prevented by propping open one water drain at each end of the car.

Several possible methods of preventing brown stain have been proposed in the past (*6*). These are (1) the utilization of lettuce cultivars tolerant to high levels of $CO_2$, (2) the use of lime in the load compartment to remove the $CO_2$ produced by respiration, and (3) ventilation of cars to prevent the accumulation of respiratory $CO_2$.

The senior author (unpublished data) has conducted studies with about one dozen cultivars of lettuce and none appear to be completely resistant to $CO_2$; however, some do appear to be more tolerant of $CO_2$ than others. In time, plant breeding, or selection, may lead to commercially acceptable cultivars tolerant to the levels of $CO_2$ encountered during shipment of lettuce.

The use of lime in conventional cars of lettuce has not been tested thoroughly, but even if it would remove the $CO_2$ adequately, it would be an added expense, and disposing of the used lime at destination would be a problem. Ventilating the car by opening the floor drains was effective in preventing the accumulation of $CO_2$ under experimental conditions. To adapt this system to commercial operations, some device must be installed in the drains to keep them either opened or closed, depending on the requirements of the commodity being shipped.

$CO_2$ levels in Transfresh modified atmosphere cars have been reduced somewhat in recent years compared with earlier shipments, probably because of increased amounts of lime and greater exposure of the lime to the car atmosphere. However, the present study indicates that further reduction in $CO_2$ levels is needed. Efforts are being made to further improve $CO_2$ scrubbing in Transfresh cars, and thereby reduce the incidence of brown stain.

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## 'PENDIX I.—ATMOSPHERE COMPOSITION IN LETTUCE LOADS SHIPPED IN ECHANICALLY REFRIGERATED CARS VENTILATED BY SEVERAL SYSTEMS

Preliminary studies conducted during June 70, tested several ventilation systems to pre- ıt the accumulation of injurious concentra- ns of $CO_2$ in railcars resulting from respira- n of the lettuce during transit. Mechanically rigerated railcars loaded with lettuce at linas, Calif., and routed through Ogden, ah, and the Chicago area were selected for study. The cars were modified as follows:

1. A Venturi tube was attached to the side of the car.
2. One inlet water drain at the "A" end (engine end) of the car was propped open.
3. Both inlet water drains at "A" end of the car were propped open.
4. Control—no alterations made (drains in normal, closed position).

The Venturi tube was attached to a 1-inch ening in the car wall. The device had an air- oop to funnel outside air, during car move- ent, past the 1-inch opening. It was hoped the sulting airflow through the tube would create suction effect to pull air from inside the car the outside. Theoretically, the resulting re- ction in inside pressure would pull outside into the car through drains or other open- gs.

Five to seven test cars utilizing each of the ur alterations were shipped over a 3-day riod (June 15-17, 1970). USDA and Pacific uit Express Co. personnel were stationed at linas and Roseville, Calif.; Ogden, Utah; Chicago, Ill.; and east coast destinations to check atmospheres in these cars. A ¼-inch plastic tube was inserted into each car at Salinas. This tube, which was sealed during car movement, was used to draw atmosphere samples at the different testing stations. The $CO_2$ concentrations were measured with portable volumetric gas analyzers.

The $CO_2$ concentrations in the test cars are shown in appendix table 5. Data could not be obtained for about half of the cars at Chicago, nor for most of the cars at the east coast, but measurements taken at other stations showed that the $CO_2$ concentration varied considerably among cars, with no apparent effect due to the different alterations to the cars.

One car, with both "A" end drains open, developed the highest $CO_2$ level (5.5 percent at the east coast) of any of the cars. Subsequent tests showed that one drain must be open at each end of a car to provide adequate ventilation.

Two of the control cars had 3.4 percent $CO_2$ at Ogden, Utah, but the $CO_2$ level had decreased by Chicago. These high early readings in transit might have been caused by the fact that these two cars were held overnight at Salinas before being shipped. $CO_2$ may not escape as readily from a stationary car as from a moving car.

The Venturi tube was ineffective probably because all water drains were in their normal, closed position, thus preventing the entrance of outside air.

TABLE 5.—*Concentration of carbon dioxide ($CO_2$) in mechanically refrigerated railcars of lettuce as influenced by car ventilation alterations. Cars shipped from Salinas, Calif., June 15–17, 1970*

| Ventilation system and test car number [1] | Concentration of $CO_2$ at indicated station | | | |
|---|---|---|---|---|
| | Roseville, Calif. | Ogden, Utah | Chicago, Ill. | East coast |
| | *Percent* | *Percent* | *Percent* | *Percent* |
| Venturi tube, drains normally closed: | | | | |
| 1 | 1.1 | ------- | 1.5 | 2.8 |
| 2 | 1.8 | 1.8 | 2.0 | ------- |
| 3 | 2.3 | 2.6 | ------- | ------- |
| 4 | 1.5 | 2.0 | 3.0 | ------- |
| 5 | 1.3 | 1.0 | .5 | ------- |
| One drain open "A" end, other drains closed:[2] | | | | |
| 6 | 1.1 | 1.1 | ------- | ------- |
| 7 | 1.5 | 1.9 | ------- | ------- |
| 8 | 1.6 | 1.2 | 1.5 | 2.0 |
| 9 | 2.0 | 1.0 | 1.0 | 0 |
| 10 | 1.1 | 1.0 | ------- | ------- |
| 11 | 1.0 | 1.3 | 1.0 | 1.0 |
| Two drains open "A" end, other drains closed:[2] | | | | |
| 12 | 1.8 | 2.1 | ------- | ------- |
| 13 | 1.3 | 1.6 | ------- | ------- |
| 14 | 1.8 | 2.5 | 3.5 | 5.5 |
| 15 | 1.0 | 1.4 | ------- | ------- |
| 16 | 2.0 | 1.6 | ------- | 1.4 |
| 17 | 2.0 | 2.0 | ------- | 1.0 |
| 18 | 1.0 | 1.3 | .5 | .4 |
| All drains normally closed (control): | | | | |
| 19 | 1.5 | 2.3 | ------- | ------- |
| 20 | 2.5 | 2.5 | 2.0 | ------- |
| 21 | 1.8 | 1.0 | 1.0 | ------- |
| 22 [3] | 2.3 | 3.4 | 2.0 | ------- |
| 23 [3] | 2.8 | 3.4 | .5 | ------- |

[1] All alterations made at shipping point.
[2] "A" end is the engine end of car.
[3] Car held overnight at Salinas before being shipped.

## APPENDIX II.—ATMOSPHERE IN A STATIONARY RAILCAR VENTILATED BY VARIOUS MANIPULATIONS OF THE FLOOR DRAINS

A new PFE railcar was made available to the USDA at Fresno for testing purposes during several weeks in May and June 1971. Studies were made with the car on a siding near the laboratory to determine how the accumulation of respiratory $CO_2$ could be prevented during shipment of lettuce.

For each test, $CO_2$ gas was rapidly introduced into the car until the atmosphere contained about 3 percent $CO_2$. Then the $CO_2$ was metered into the car at a rate comparable to that which would be produced by respiration of a carload of lettuce at 38° F., a common transit temperature for lettuce (respiration at 48° was simulated in one test). The car was empty except for large bags of air which were placed

in the load compartment to simulate the space occupied by a load of lettuce. The mechanical refrigeration unit was running during all tests, and the thermostat was set at 34°.

A small electric fan was placed near each of the water drain openings under the car to try to simulate airflow past the openings during normal car movement in transit. The airspeed past the drain was equivalent to a constant running speed of about 37 miles per hour. Some of the tests were conducted with the drain fans on and some with the fans off.

The various conditions tested and their effect on the level of $CO_2$ in the car are shown in appendix table 6. Rather than increasing the rate of air exchange through the drain openings as expected, the portable fans impeded air exchange, apparently because they created an air curtain over the drain openings. During actual rail transit, car speeds and air currents about the drains continually change, in contrast to the condition created by the portable fans. Therefore, the tests conducted with the portable fans off are probably more representative of what would happen during railcar movement than those conducted with the portable fans on.

The effect of the portable fans in changing $CO_2$ levels in tests 6 and 8 is shown in figure 2. All conditions were the same in these two tests, except for portable fan operation. The fans were on in test 6 and off in test 8. In both tests, one of the two drains was open in each end of the car. In test 6, the $CO_2$ began to build up in

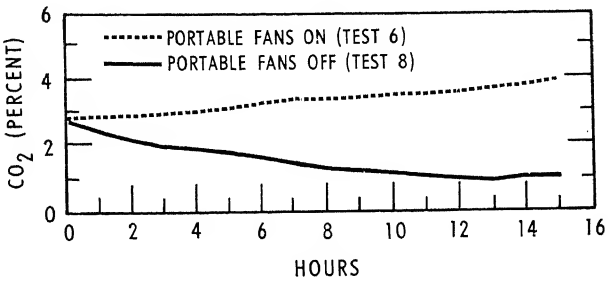


**FIGURE 2.—Effect of portable fan operation at drain openings on carbon dioxide ($CO_2$) levels in a stationary railcar. In each of the two tests, one water drain was open at each end of the car. The $CO_2$ level was 2¾ percent at the start of the tests. The $CO_2$ was then metered into the car at a rate comparable to that produced by the respiration of a carload of lettuce at 38° F.**

TABLE 6.—*Changes in carbon dioxide ($CO_2$) concentrations in a new, stationary railcar as influenced by indicated position of drain openings*

| Test No. | Drain position [1] | Portable fans at drains [2] | Compressor and car fan speed | $CO_2$ level in car during test [3] |
|---|---|---|---|---|
| 1 | All drains open | On | Normal | Decreased. |
| 2 | All drains open | On | Normal | Decreased. |
| 3 | No drains open | On | Normal | Increased. |
| 4 | Both "A" drains open | On | Normal | Increased. |
| 5 | Both "A" drains open | On | High | Increased. |
| 6 | One "A" and one "B" drain open | On | Normal | Increased. |
| 7 | All drains open | Off | Normal | Decreased. |
| 8 | One "A" and one "B" drain open | Off | Normal | Decreased. |
| 9 | Both "A" drains open | Off | High | Decreased. |

[1] Two water drains at "A" (engine) end and two at "B" (brake) end of car. Drains were closed unless otherwise indicated.

[2] One portable fan at each drain directed at 90° angle to the opening. Air movement at each opening calibrated at 37 m.p.h. during fan operation.

[3] The $CO_2$ concentration in the car was brought to a constant level (about 3 percent) before each test and was metered into the car to simulate respiratory $CO_2$ production by a load of lettuce at 38° F. (48° in test 2).